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The Impacts of Reflective Writing on Peer Evaluations in Engineering Design Courses

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Abstract

Like many undergraduate engineering programs, students in Baylor's Engineering Design Courses participate in multi-disciplinary teams in semester-long design challenges as part of a two-course sequence required in the undergraduate curriculum. In addition to the structured technical design process, design-course students are also required to complete individual development assignments designed to enhance each student's growth as an individual contributor and team member. The program requires students to conduct peer evaluations and self-evaluations at approximately the mid-term point as well as during the final week of the semester. Using Purdue's Comprehensive Assessment of Team Member Effectiveness (CATME) evaluation system, students are required to rate themselves and teammates on the standard CATME dimensions, as well as provide constructive comments that are tailored for each teammate describing specific behaviors to start, stop, or continue. Unique to our institution's program, students are assessed on their ability to provide actionable, constructive feedback to each teammate beyond superficial peer comments such as "you are doing a good job." Additionally, each student is required to write an individual development plan to both reflect upon the feedback received and set practical improvement goals for the semester and desired professional growth after the course concludes. Students must objectively analyze why they received any critical feedback and not simply justify behavior. This work will describe the approach used in these assignments, the detailed instructions provided to students, and the results of performance metrics. The performance metrics are investigated regarding the hypothesis that peer evaluations will show improvement trends for students that complete individual development plans as compared to students in legacy versions of these design courses who did not have this requirement.

Introduction

In undergraduate Engineering Design Courses, students universally must address a technical challenge and develop an adequate solution that is suitable to address the project technical, schedule, and budget requirements. In concert with that technical development process, our institution's students are also introduced to the professional development techniques often employed by industry to holistically look at an individual's performance using 360-degree feedback where perspectives from a manager/supervisor are used in conjunction with those from peers. In a dissertation focused on validation of 360-degree feedback assessments, Mahlke[1] discussed the prevalence of multisource performance feedback in industry and that an estimated 90% of Fortune 1000 companies use the technique in some form. Though employees may have mixed feelings about the practice in the workplace (e.g., angst about providing thoughts on a co-worker that are brutally honest vs. trying to make a friend look great to the supervisor), Peiperl[2] proposed some techniques to ensure its effectiveness. The authors of this paper can speak specifically about our own industry experiences where 360-degree feedback was used across numerous industries and organizations. Transitioning to the academic realm, Pappas[3] discussed the effectiveness of using multi-source feedback to promote student success in the context of STEM courses, not limited to engineering.

Instructors of courses that utilize teamwork, who have reviewed peer-to-peer student feedback, will also know the value it can have for amplifying/confirming perceived knowledge of team dynamics. The student feedback also may provide more information about individual student performance when teams work outside of class. This work seeks to evaluate the performance metrics for indications that there is a benefit for individual students working in a design team who are required to author reflection papers in response to peer review feedback, with analysis of students starting both above and below average in the results of the first peer evaluation.

Pung and Farris[4] describe using the CATME system for peer reviews in a design course, with some basic questions for each student to consider and respond after seeing peer ratings. The questions prompted to students from that work were:

- Compare and contrast your self-evaluation to the evaluation of your peers. Discuss any differences.
- How will you improve your performance in the future? The Catme.org website gives specific information on improving your performance.

Pung and Farris noted it was difficult to draw very sound conclusions from the student responses. Most students provided some strategies for improvement, but just posing the above questions did not result in quality reflections[4]. Barr and De Clerk[5] discussed interesting team dynamic analysis using CATME evaluations accompanied with reflections across a sequence of undergraduate courses (including Capstone Design). The concluding remarks of their work mentioned how well CATME peer comments can provide insight for team performance, "if they use it." Making the reflective comments a higher point value in the assignment would emphasize the importance of these comments and encourage students to take full advantage of the opportunity to provide their peers quality feedback.

Clinical Faculty at Baylor University established a robust 360-degree feedback process with written student reflection in the Capstone Design course several years ago. The objective was to mimic the industry practice of robust 360-degree reviews (to the extent possible) to professionally grow students who will soon graduate (with many directly heading to positions in industry). Higher-level learning objectives are also promoted, to include the overall need to equip students in the general practice of reflective writing. Wheeler and McDonald[6] noted the need for all engineering students to practice reflection as a means to demonstrate more thorough understanding of undergraduate content. Their work discussed the need for equipping engineering students for real-world problems that are indiscriminate and where technical knowledge alone will not be enough to craft a proper solution. A writing assignment helps the students to think more comprehensively, often requiring multiple sessions of reflection to capture thoughts properly. Referring to Schön's reflective practitioner[7], Wheeler and McDonald state:

> *The habits developed when writing – thinking comprehensively, expecting to rework the initial results, and realizing there is no one "correct answer" – are indispensable…*[6]

Buswell, Jesiek, et. al[8], noted in a 2019 survey of engineering instructors the overall lack of satisfaction in engineering students' writing skills, with the unsurprising feedback that a lack of time in the curriculum was a primary reason for not doing more to address the deficiencies via additional writing assignments. The work noted that additional support resources such as graded examples or rubrics would be a key asset to help more instructors incorporate additional writing content.

In the Fall 2022 semester, the course instructors introduced the robust 360-degree feedback concept to the Junior Design Course (the first of a two-course Design sequence). This was just one of several changes to this course in Fall 2022, aimed at providing additional structure to the assignment instructions and overall expectations of students (both from a team and individual perspective). The instructors implemented a course-wide shift from formative to summative assessments via introduction of formal work instructions and grading rubrics for all assignments, including the expectations for quality of feedback in peer review comments. As just one example, the quality of peer-to-peer feedback became a graded assessment rather than a completion grade. This shift helped to enhance overall quality of student deliverables in the course due to clearly conveyed expectations on team as well as individual student deliverables (such as reflection papers and design rationale reports). As will be seen in this work, raising the level of expectation of the students in the course resulted in an unanticipated upward shift in overall peer reviews across the board (including the initial peer review scores). The fundamental goal of these additions remained the same as mentioned above with the Capstone Course: to professionally grow students by giving them exposure to industry practices of team-based product design (to include 360-degree peer evaluations) while still in the undergraduate experience.

The authors (who teach both courses in the two-course design sequence) have already observed improved performance in the Capstone Design reflection assignments for students who received an introduction to the process during the Junior-level course. Of note, the design courses at the institution are multi-disciplinary where the majority of design teams are formed with a mix of students majoring in Mechanical, Electrical and Computer, and General Engineering. Some of these students may be teamed with students they have had no previous interactions prior to the course.

Reflective Writing Process

Following week 5 in the Junior-level course, students conduct initial peer evaluations and complete a self-evaluation. Each student will evaluate his/her own performance on the same criteria that he/she evaluates each teammate. This provides an insightful indication of how a particular student is performing in the eyes of teammates compared to the student's own perspective.

Specific assessment criteria are prompted based on the Teamwork Dimensions from Purdue's CATME peer evaluation system[9], the tool our program uses for administering the Peer Review inputs in design courses. Previous work describing the tool's effectiveness for improving teamwork and completing peer reviews are apparent across multiple institutions and course types. A few examples (though not exhaustive) are work such as Berry, Huang, and Exter[10], Beigpourian, Ferguson, Berry, Ohlan, and Wei[11] and Mahmood, Choudhary, and Qurashi[12].

The reader is most likely familiar with the CATME system, but the five evaluation dimensions include[9]:

i. Contributing to Team's Work
ii. Interacting with Teammates
iii. Keeping the Team on Track
iv. Expecting Quality
v. Having Related Knowledge, Skills, and Abilities

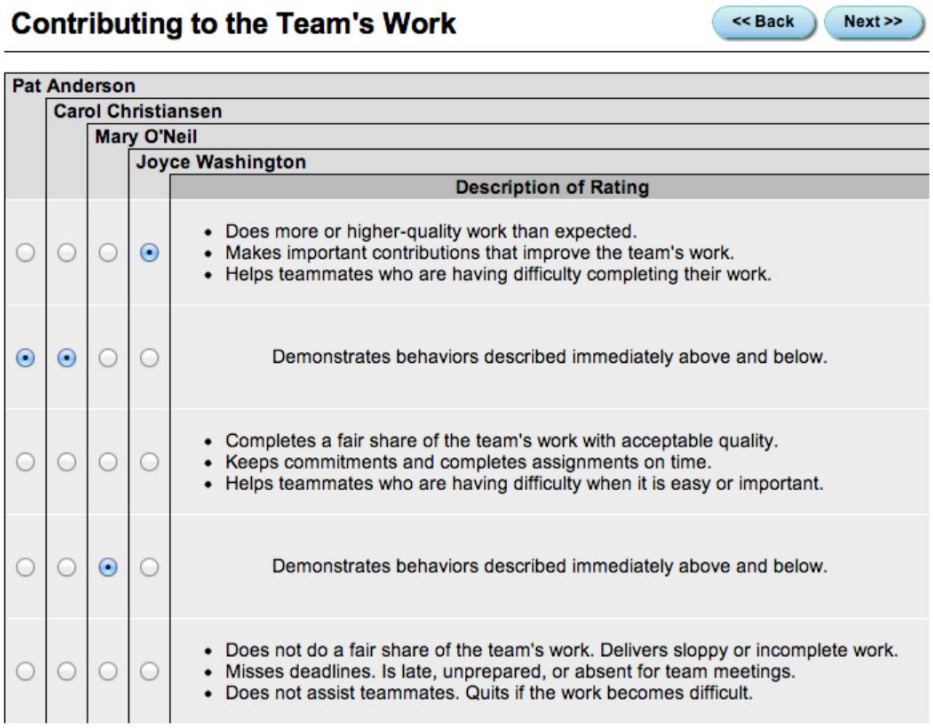

Figure 1. Example Peer-Evaluation Screenshot on a Teamwork Dimension in CATME[9]

Each student must rate every team member (and conduct a self-assessment) based on the scale shown in the example of Figure 1 by choosing the behaviors that most closely describe the perceived performance of each student. For purposes of the reflection process, students are instructed to view the ratings on the five-point Likert scale, with 'five' corresponding to the highest performance and 'one' corresponding to the lowest performance. This aligns with the numeric scores that the CATME system provides to instructors following a completed peer assessment, though the students just receive an indicator on the scale as feedback rather than a specific number.

Requirements for Substantive Peer Comments

In addition to the standard CATME dimensional assessment, students must also provide comments to support and amplify the rationale for the rating. The comments must be substantive, with specific examples to justify their thoughts on teammates' performance. The following guideline is provided that each student must make an actionable comment on at least one of three behavioral aspects:

1. START: something that the individual currently has not been doing but should start doing to enhance the team's performance.
2. STOP: something counterproductive or unnecessary that the individual needs to cease doing going forward
3. CONTINUE: something that the individual has done well and should continue to do for the remainder of the project

Prior to implementing the mandatory START/STOP/CONTINUE guidelines to the peer comments, many comments written by students were not helpful or substantive. Examples of poor, unacceptable comments include:

- "Continue being a great teammate!"
- "You contribute great ideas."
- "Continue being a great <insert role here>!"

These types of comments are clearly not helpful as they provide nothing specific for a student to use for reflection and growth and are included as examples of what not to do in the assignment instructions. Furthermore, students are asked to include specific examples from interactions or team meetings to justify the comments. This greatly helps the student receiving the feedback to understand the specific advice or issue more clearly. On occasion, students admit that they struggle to understand why a peer would make a certain criticism and even directly write about the confusion in the reflection assignment. Enforcing inclusion of the specific examples helps each recipient to see the evaluator's point of view. In this view, students learn to understand that "the other person's perception is reality" for that person. The student receiving the feedback can also use the specific examples to help develop an action plan to address each critique or to enhance the areas where performing well.

Individual Development Plan

Students receive anonymized feedback from the peer evaluation and assess their performance via a written reflection including performance improvement goals for the remainder of the semester. Each student formally documents the reflection and goals via an Individual Development Plan (IDP). The IDP must specifically address the ratings received via the CATME five-point scale on at least two of the dimensions (student's choice) as well as any dimension with a score of three or less. The latter indicate areas where improvement could be most helpful both for the individual and the team, so students are required to specifically discuss/address those dimensions in the IDP.

Additionally, students are asked to objectively reflect on the peer-to-peer comments and not to merely justify behavior or dismiss a comment as unwarranted. Each student should view the feedback as genuine. If the feedback seems wrong from the perspective of the receiver, the receiver should objectively consider why the evaluator has that point of view and what actions can the receiver do to address the situation through better communication or behavior change(s).

SMART Goals

Each of the student goals must have a description that is Specific, Measurable, Achievable, Relevant, and Time-Bound (SMART)[13]. Using the simple SMART acronym, each student must develop at least one actionable goal (preferably more) that they can actively strive to achieve for the remainder of the project. Students are assessed on how well they write goals that address each of the SMART criteria. Students often learn later in the semester that the goals sometimes lack enough specificity when they attempt to assess their own performance against them, hence why it is vital to provide specific instructions on developing the goals.

Students conduct a final peer evaluation (with one week remaining in the semester) at the point they have concluded the final verifications of their design projects. They follow the same process as at mid-term by completing the CATME assessment along with peer-to-peer comments. They again assess their own performance, both from comparison of their thoughts vs. their peers as well as how they performed against their own action plan developed approximately eight weeks earlier. Students assess how they have improved (or not) based on the deltas in scores on the five dimensions since the first peer review, as well as reflect on any changes in peer-to-peer comments in another reflective writing assignment (a second IDP). While the reflections, actions, and goals set in this assignment will not be able to be worked on extensively in the course, they are important things to consider for growth and to be successful in future team-based projects as well as in new roles following graduation (whether industry or graduate school). Each student is prompted to consider:

- Were the START, STOP, CONTINUE comments from the first peer review adequately addressed via evidence in the second peer review?
- How did the contribution scores in the dimensions change from the first peer review? For the better or worse? What caused the change?

As mentioned above, substantive point values are a key motivator to getting students to take an aspect of any assignment seriously. Figure 2 shows an example depiction of the grading rubric used

for assessment of the IDP. One can see the emphasis on quality of the reflective writing to earn an acceptable grade. Emphasis is placed on the analysis of the CATME dimension scores, the response to peer-to-peer comments, and the quality and specificity of the improvement plan. Of note, this work bases the IDP responses around CATME scores as this is the system we use at our institution. The IDP framework is foremost about holding students accountable for reviewing and responding to peer feedback, so this construct could be easily applied to other peer review systems as needed.

Criteria	Ratings			Pts
CATME ratings and score included	**5 pts** **Full Marks**	**0 pts** **No Marks**		5 pts
Comments/Observations on at least 2 of the 5 dimensions	**10 pts** **Two dimensions discussed**	**5 pts** **One dimension discussed**	**0 pts** **No Marks** No dimensions	10 pts
Quality/thoughtfulness of observations i. Discussion of widest gap between self-evaluation and group evaluation ii. Reflection on cause of gap or perception	**20 to >0.0 pts** **Variable Points for Quality**	**0 pts** **No Marks**		20 pts
Peer to Peer Comments included	**5 pts** **Full Marks**	**0 pts** **No Marks**		5 pts
Discussion on peer comments received	**10 pts** **Full Marks**	**0 pts** **No Marks**		10 pts
Quality of discussion of peer comments i. Reflection on at least one peer comment ii. Degree of reflection / introspection and not justification of the observed behavior	**20 to >0.0 pts** **Variable Points for Quality**	**0 pts** **No Marks**		20 pts
Quality of the improvement plan i. Clear, actionable plan identified ii. Plan will address inadequacies or strengthen positives	**25 to >0.0 pts** **Variable Points for Quality**	**0 pts** **No Marks**		25 pts
Template Used Appropriate Word document template used to write the report	**5 to >4.0 pts** **Full Marks** Template used and document is free from spelling/grammar errors.	**4 to >0.0 pts** **Partial Marks** Spelling or grammar mistakes distract from the content of the report	**0 pts** **No Marks** Template not used. Large amount of spelling/grammar issues.	5 pts

Figure 2. Example of Individual Development Plan Grading Rubric

Data Review and Assessments

To compare peer review data, a control group was selected from the three semesters prior to the IDP introduction (Spring 2021, Fall 2021, Spring 2022) with the three semesters that include the IDP assignments (Fall 2022, Spring 2023, Fall 2023) as an experimental group. The specific Peer Review contribution factor generated by CATME was evaluated for overall changes, as well as trends within a given semester between subsequent peer evaluations. Of note, the control group semesters had three peer evaluations (an initial, mid-term, and final) while the experimental group had two peer evaluations (mid-term and final). This change was made to give students more time to establish good habits as a team prior to the initial evaluation, but also to not overly burden the students with too many new assignments in an already busy curriculum.

As seen in Table 1, the experimental group showed an increase across the mean scores of all five CATME dimensions. These mean shifts ranged between +0.19 to +0.25, corresponding to an increase ranging from 4.86 – 6.23%. Using a t-test assuming unequal variances, we see P-values ranging between $1.23e^{-4}$ to $1.83e^{-8}$. Thus, we are highly confident that these mean shifts are statistically significant. Since these increases occur even in the first peer review (before the first reflective writing assignment by the student), it is not an apparent conclusion that the existence of the IDP created an increase in dimensions scores or contribution factors between initial and final peer evaluations. In fact, the data shows there is no statistically significant increase between the control and experimental groups when comparing differences between initial and final scores in each semester. In both groups, the raw ratings increased from initial to final in the five dimensions. One then asks, what causes the overall consistent, upward shift in ratings of all the dimensions across all three semesters of the experimental group? The existence of a reflective writing assignment with robust instructions and assessment criteria could be a contributing factor. Students know in advance they will be assessed on how well they follow the peer review instructions and also know in advance they must reflectively write about the peer review scores they receive. This foreknowledge could be a factor to students more diligently contributing to their team, knowing that the peer review data will be taken very seriously by the instructors.

Control Group	Averages			Averages			Averages			Averages			Averages		
	Contributing to the Team's Work			Expecting Quality			Having Knowledge, Skills, etc.			Interacting with Teammates			Keeping the Team on Track		
	Initial	Mid-Term	Final	Initial	Mid-Term	Final	Initial	Mid-Term	Final	Initial	Mid-Term	Final	Initial	Mid-Term	Final
Spring 2021	**3.95**	**4.04**	4.05	**4.01**	**4.11**	4.01	4.08	4.09	4.09	3.99	**4.00**	**4.08**	3.95	3.92	3.93
Fall 2021	**3.86**	**4.03**	4.03	**3.97**	**4.09**	4.13	**3.94**	**4.03**	**4.08**	**3.82**	**3.91**	**3.98**	**3.75**	**3.88**	3.93
Spring 2022	**3.96**	**4.09**	4.08	4.23	4.16	4.21	**3.98**	**4.11**	4.13	4.09	4.11	4.11	3.90	**3.90**	**4.06**
Grand Mean (unweighted)		4.01			4.10			4.06			4.01			3.91	

Experimental Group	Averages			Averages			Averages			Averages			Averages		
	Contributing to the Team's Work			Expecting Quality			Having Knowledge, Skills, etc.			Interacting with Teammates			Keeping the Team on Track		
	Initial	Mid-Term	Final	Initial	Mid-Term	Final	Initial	Mid-Term	Final	Initial	Mid-Term	Final	Initial	Mid-Term	Final
Fall 2022		4.21	4.19		4.33	4.35		4.25	4.26		4.13	4.19		4.03	3.98
Spring 2023		4.28	4.35		**4.29**	**4.43**		**4.25**	**4.36**		4.26	4.28		**4.10**	**4.28**
Fall 2023		4.22	4.28		**4.23**	**4.37**		4.32	4.36		4.26	4.27		**4.02**	**4.18**
Grand Mean (unweighted)		4.25			4.33			4.30			4.23			4.10	

Delta	**0.25**	**0.23**	**0.24**	**0.22**	**0.19**
P-value	**9.89E-06**	**1.83E-08**	**1.36E-06**	**3.37E-06**	**1.23E-04**

(t-Test, Two Sample Assuming Unequal Variance)

Table 1. Observed Mean Shifts of Dimension Scores between Control and Experimental Groups

To analyze differences in contribution factors between the control and experimental groups, we have defined outcomes as a series of Bernoulli events as follows:

- E_0, where success is defined as receiving a contribution factor greater than or equal to one in the initial peer evaluation.
- E_{1+}, for students with successful outcomes in E_0, where success is defined as maintaining contribution factors greater than or equal to one in subsequent peer evaluations.
- E_{1-}, for students with unsuccessful outcomes in E_0, where success is defined as receiving a contribution factor greater than the contribution factor received in the initial peer evaluation in subsequent peer evaluations.

Statistical significance of differences observed between the control and experimental groups have been determined by calculating binomial probabilities for outcomes in the experimental group (treating each observation as a trial and determining numbers of successes as defined above) using corresponding ratios of successes and trials from the experimental group as probabilities of success.

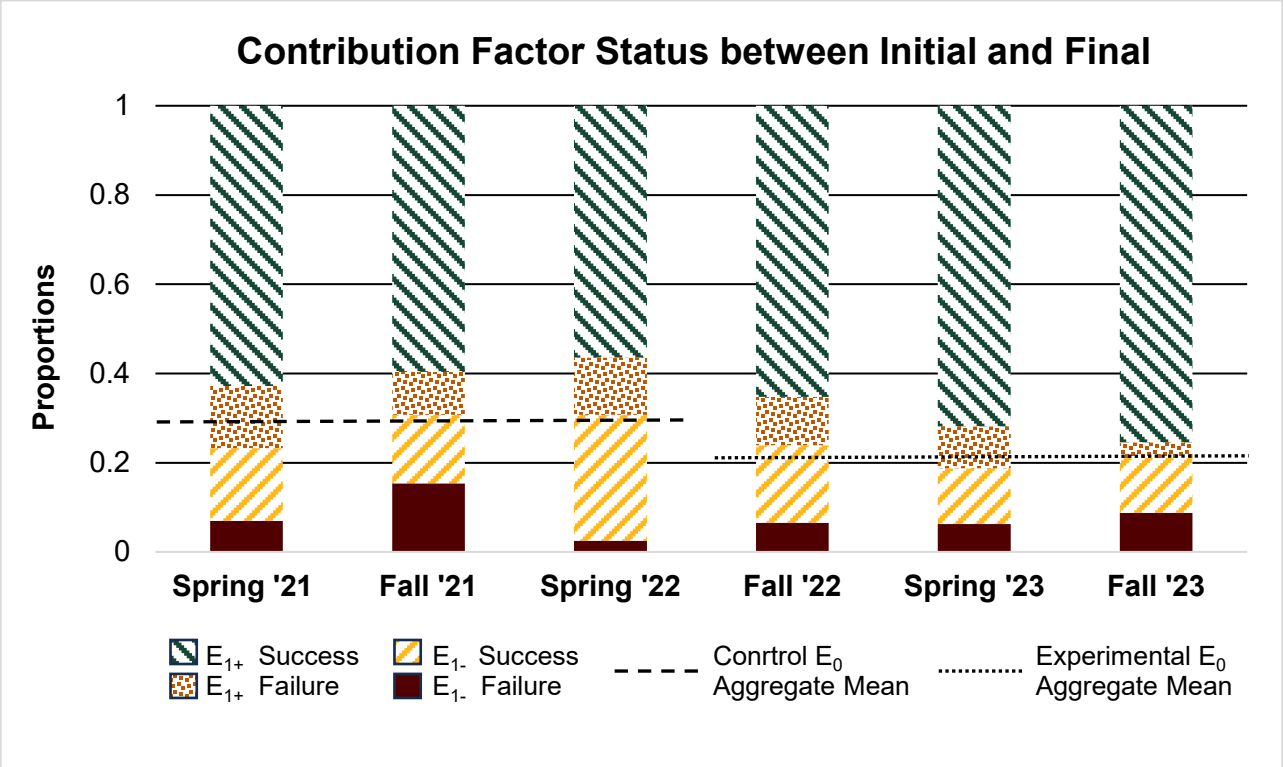

Figure 3. Comparison of Contribution Factor Status Between Initial and Final Peer Reviews Among Control Groups and Experimental Groups

Analysis of each semester is shown graphically in Figure 3 via a stacked bar plot for each semester. The success or failure of events in each semester are stacked (from top to bottom) in the following order: E_{1+} success, E_{1+} failure, E_{1-} success, and E_{1-} failure. There are a few fascinating effects that are found through this analysis:

1. The proportions of students with CATME contribution factors greater than one in the first peer evaluation increased after implementation of the IDP (this is E_0, the increase in the success rate from 71.6% in the control group to 79.0% in the experimental group is considered statistically significant with p=0.0182).
2. The proportions of students with CATME contributions factors greater than one in the first peer evaluation that decreased to contribution factors less than one in a subsequent peer evaluation went down in the experimental group (this is E_{1+}, the increase in the success rate from 83.3% in the control group to 90.2% in the experimental group is considered statistically significant with p=0.0183)

3. The proportions of students with CATME contributions factors less than one in the first peer evaluation that increased in a subsequent peer evaluation also decreased in the experimental group (this is E_{1-}, the decrease in the success rate from 68.4% in the control group to 62.9% in the experimental group is not considered statistically significant with p=0.2949). On this point it is also worth noting that the overall percentage of students with CATME contributions factors less than one in the first peer evaluation that decreased in subsequent peer evaluation is lower in the experimental group (7.19%) than in the control group (8.95%) also decreased in the experimental group; however, this effect is not considered statistically significant with p=0.2605.

Both metrics are obviously positive trends in peer evaluation scores. More of the students that initially performed well continued to perform well, and there were fewer students who started strong but declined during the semester. Based on this data, one can conclude that a benefit of the IDP is maintaining strong performing students through a reflection and affirmation of their strong performance.

Conclusions and Future Work

The presence of the reflective writing assignments has shown some positive outcomes as demonstrated in the previous section. From an objective standpoint, there are some metrics that have proven important effects, but more data is required for further analysis. As noted in the above assessments, some outcomes only include a small percentage of the students, so more data is required in future semesters to determine significance. We plan to continue monitoring this data in the coming semesters to look for additional insights.

Though not specifically analyzed, one might inquire what number of peer reviews (i.e., a sequence of three or two) during a semester yield better outcomes. The available data doesn't support an objective advantage to either approach in terms of improvement to CATME scores. Based on instructor observations in these design courses, two peer reviews with associated reflective writing have proven effective without overburdening students in an already full curriculum. From a professional development standpoint, these assignments have value in preparing students to critically think on their own performance and ways they can better themselves individually and as part of a cohesive engineering team.

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